Introduction to the Brain Through Embryology

Introduction

The process of forming the entire nervous system is immensely complex. The point of this lesson is to use embryology to identify the structures you will encounter throughout the module, a sort of introduction to anatomy. It will also reveal the patterns that are repeated time and time again throughout the nervous system. We'll focus mostly on the spinal cord, do a gentle dive into the more advanced structures of the hindbrain, midbrain, and forebrain, and will also call out some of the elements of the nervous system as you have encountered them in other organ modules.

We are naughty embryologists. The correct words are rostral (towards the head), caudal (towards the tail), ventral (belly-side), and dorsal (backside). Those are accurate terms. However, we (and probably you, too) naturally think of the embryo and fetus as an upright adult. We WANT you to do that. Always envision the embryo as if the head is up (superior), and the feet are down (inferior). That way, the terms you are already familiar with for an adult human will apply. Therefore, in our writing, anterior means ventral and posterior means dorsal. For example, a "dorsal root ganglion" has projections into the posterior horn of the spinal cord. In the upright human, those two things are right next to each other, in back, and so dorsal root ganglion is interchangeable with posterior root ganglion.

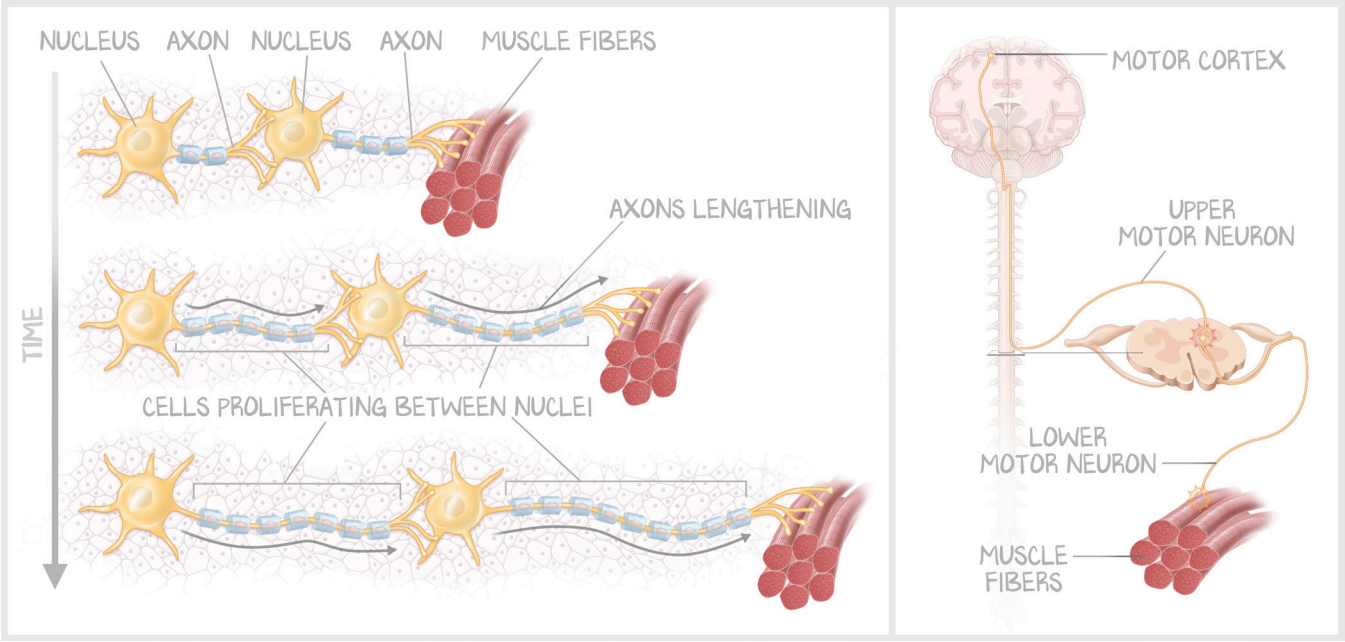

Figure 1.1: Nothing Migrates
Neural crest cells do migrate . . . In an aqueous environment in the early days of the embryo. Learn that nothing migrates. As cells divide, forming organs, growing the size of those organs, the space in between two cells that were together at day 21 may be trillions of cells wide by day 267. This is a representative consideration of the arrangement of the CNS. One neuron depicts a nucleus destined for the motor cortex, one neuron depicts a nucleus destined for the spinal cord, a muscle bundle depicts cells destined to become muscle in the periphery, and the neurons' axons are representative of the tract. The point of this is that the cells within the central nervous system nucleus will become a nucleus from a common progenitor—the nucleus will consist of one type of neuron. The cortex will become far away from T6, and the muscles that those motor neurons innervate will become far away from the spinal cord. The connection has already been made, the replication of other cells provides the distance in between.

Nothing "migrates" during development (in weeks 2–3 some things move, but it's better to start with "nothing" migrates). There are no roads to travel on, cells don't have feet, and once there is a bloodstream, only the cells of blood use the bloodstream. However, one cluster of cells can get farther away from another cluster of cells. The only way that happens is if another cluster of cells proliferates between the first two. The embryo gets larger as more and more cells proliferate. This is especially important for the nervous system. But "migration" is a convenient term, and is used ubiquitously in embryology, so we're going to use it, too. Just know that the "movement" of cells is actually only relative to other cells and that it is caused by the division of cells. This is what we mean every time we say that cells "travel" or "migrate."

In the adult, the neuron cell bodies are mostly within the central nervous system: brain, brainstem, spinal cord. They are connected to the thing they innervate by axons. The central nervous system still has some maturing to do after birth. But in general, and especially in adults, neurons don't divide, and their axons don't move. That means that the progenitor cell that will eventually become a neuron with an axon that connects the spinal cord to the toe muscle must start embryogenesis with a progenitor cell with an axon already attached to the progenitor cell that will become toe skeletal muscle. As cells divide, the cells that will become the thigh, knee, and lower leg will push the toe muscle farther away from the spinal cord. As they do, the axon of that neuron lengthens.

Finally, cell types grow up near their own kind. The progenitor cell that will make all the motor neurons in the spinal cord at the level of T2 will replicate to ensure that there are enough motor neurons to innervate all of the skeletal muscles on its side of the spinal cord. That means, inherently, that neurons of one type are always clustered together. That cluster is called a **nucleus** in the central nervous system (CNS) and a **ganglion** in the peripheral nervous system (PNS). And because axons are the means of communication between neurons of the same tract, axons from neurons of one nucleus will travel with all the other axons of all the neurons of that one nucleus. Clusters of axons of a nucleus traveling through the CNS are called **fascicles**. The only time axons of different nuclei are found together is in **peripheral nerves**.

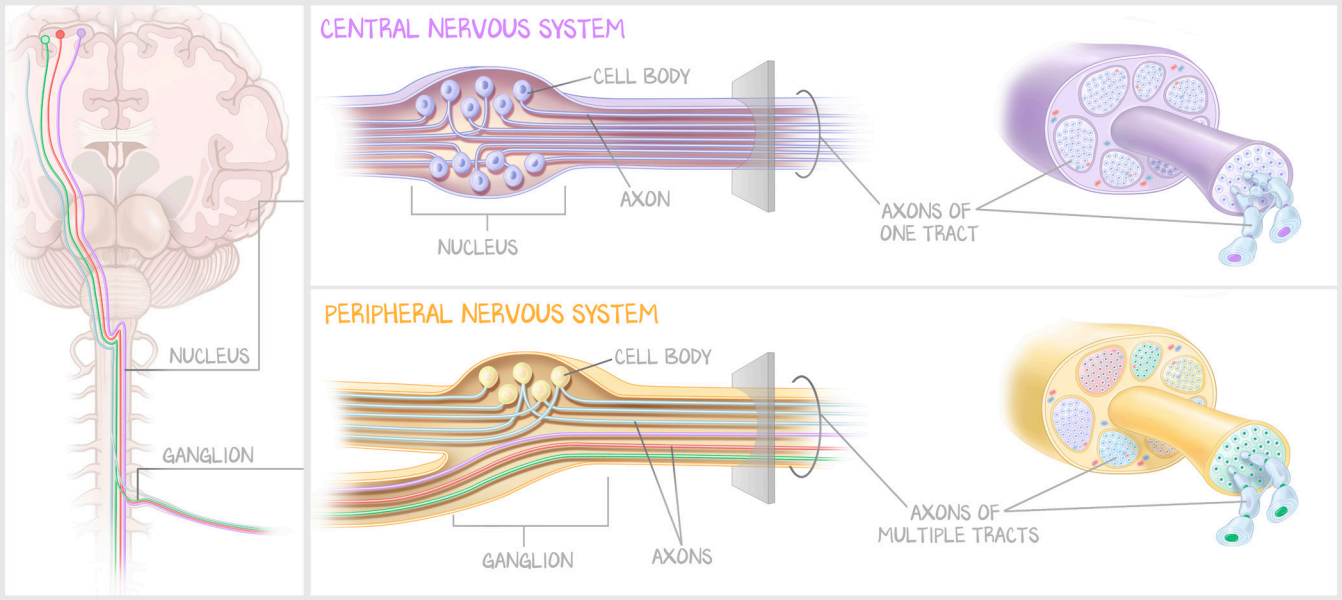

Figure 1.2: Tracts Are the Same Way
Because each neuron has an axon, and neurons of a common nucleus replicate near like-minded nuclei from a progenitor, the axons of those nuclei must, therefore, be physically near each other. To protect the tract, central nervous system fascicles, made by the glial cells that service those axons, enclose the axons. Nuclei don't mix. Fascicles don't mix. The only time they can mix is in peripheral nerves, where a nerve carries the tracts of multiple nuclei.

We're going to go into detail about what those last two paragraphs mean in the next 20 lessons. If you aren't totally comfortable with those concepts right away, don't worry. We left out a lot of information. You're going to realize that each lesson builds on the one before it. Sometimes we are redundant, saying the same thing in one lesson and then again ten lessons later. That's because the central and peripheral nervous systems, somatic and autonomic, **are interconnected**. Connections exist between neurons, axons, and those axons' synapses. The nervous system runs on electricity (action potentials) and synaptic clefts (neurotransmitters and receptors), just like we taught you in General Physiology.

This first lesson uses embryology to define the peripheral nervous system, spinal cord, brainstem, and cortex. The goal of this lesson is not to master the embryogenesis (many names are involved, and structures get renamed over and over) but to see where certain ganglia and nuclei are, understand why they are where they are, and at least familiarize ourselves with all the structures before approaching the rest of Neuroscience. And remember, neurons exist in nuclei, and their axonal tracts occupy just about everything else. There are support cells between axons, but all of the gross anatomy and histological appearances are either neurons in nuclei or axons in fascicles. Humans named parts of the nervous system because they have a visible distinguishing appearance on gross anatomy. It was a convenient way for humans to categorize and catalog. But what that did is hinder the comprehension of what those structures are actually made of. The convenience of naming different parts of the brain and brainstem ended up being arbitrary. A tract has mass, and it takes up volume. And those tracts, adding volume, are what cause the external appearance of the central nervous system. Nuclei are where they are. Axons are where they are. Everything is interconnected, interconnected by axons. And the only thing that moves down or up the tracts is electricity, the action potential.

Commonalities

The development of the nervous system is very complex. But some patterns emerge.

The first is that many regions form through an **invagination of the ectoderm** into the **underlying mesoderm**. The whole nervous system is derived from ectoderm. Not the skin's ectoderm, but specialized neuroectoderm. Between ectoderm and endoderm is mesoderm. Neuroectoderm separates from the ectoderm of skin and develops in an ocean of mesoderm. In the beginning, mesoderm pushes ectoderm around. Later, mesoderm provides the tissue for ectoderm to grow into.

The second is that **neural crest cells** migrate (really migrate) throughout the body, becoming the ganglia of the sensory tracts as well as the autonomic ganglia. They are neurons and send their axonal projections out to the periphery. Neural crest cells **become the entire peripheral nervous system**. They also become many other things, but we want you to see that there is a stripe of cells—the neural crest—that separates from the skin ectoderm as well as the neural ectoderm. Neural crest cells can migrate (really migrate and also proliferate) away from the central nervous system and be anywhere.

Neurulation

We will cover all the steps that lead up to neurulation in Reproduction. Discussing neurulation here, we begin with the trilaminar disc. **Ectoderm** is the sheet of cells on top with the amnion above it. **Endoderm** is the sheet of cells on the bottom, with the yolk sac below it. Between ectoderm and endoderm is the sheet of **mesoderm** cells. Mesoderm, at this point, is more than a sheet. It has already begun to replicate, increasing in height. Embryologists divide the mesoderm into axial, intermediate, and lateral mesoderm. You don't care about that, here. What you do care about is the mesodermal **notochord**, right smack in the middle of this trilaminar disc. It is present across the length of the embryo. It is a tube that will, in the adult, form intervertebral discs, padding for the vertebra. But at this point, around day 20, it is responsible for inducing embryogenesis of the entire nervous system.

The notochord exposes the ectoderm directly above it to high levels of a molecule abbreviated BMP. These ectoderm cells, having been stimulated by their environment, will become **neuroectoderm.** They replicate and thicken at their base, forcing the ectoderm to rise. At the same time, the notochord induces the mesoderm immediately flanking the notochord to proliferate up into the ectodermal layer, faster than the ectoderm. This creates two ridges, each with neuroectoderm continuous with the neuroectoderm above the notochord. These rising ridges are termed **neural folds**. Atop these neural folds are **neural crest cells**. They started immediately adjacent to the ectoderm that was transformed into neuroectoderm. They were further away than neuroectoderm, but closer than the surrounding skin ectoderm. As the neural folds push up, the neural crests riding atop the crest of the wave, the two crests collide. Mesoderm proliferates over the collision, separating the neuroectoderm and the neural crest cells—now continuous with each other—from the skin ectoderm. This collision and separation from the skin forms a ring of cells, called the **neural tube**.

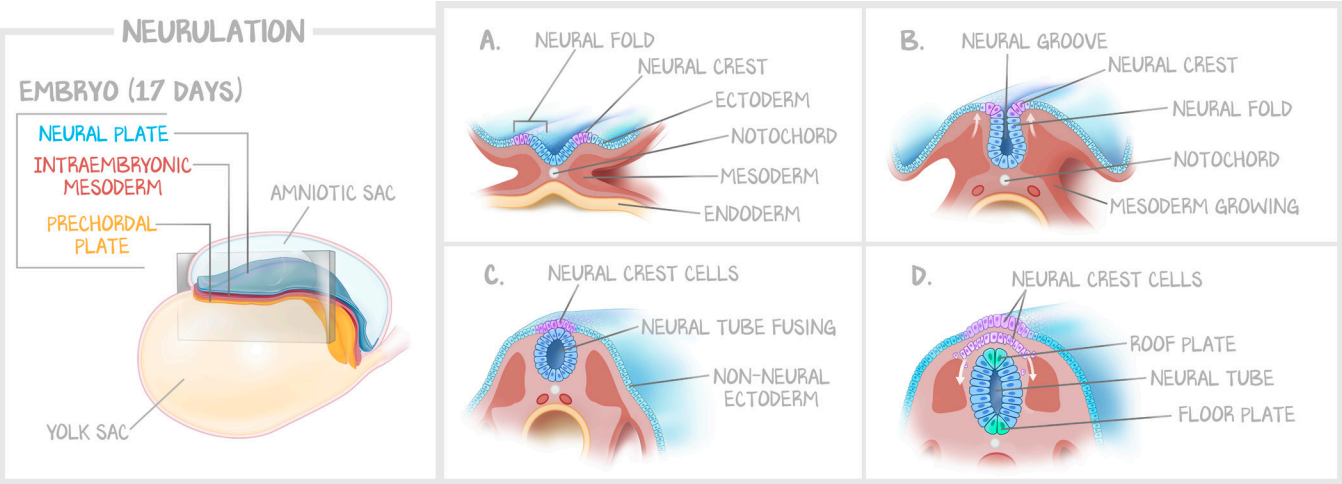

Figure 1.3: Neurulation and Neural Crest Formation
Mesoderm migrates between the neural crest and the ectoderm of the neural folds as the neural folds fuse. This sheet of cells is continuous with the lining of the amnion and will become skin. The neural folds fuse and form the neural tube. Mesoderm also separates the neural crest from the neural tube.

As the neural crest cells prepare to leave, they separate from the neural tube and begin their journey. A neural tube made of neuroectoderm is left behind. The **neural tube** will become the **central nervous system**. The **neural crest cells** will become the **peripheral nervous system**. This process starts at the primary centers of neurulation, then continues from them in both directions—caudally and cranially. The progressive "zipping up" of the neural tube conveys a temporal and spatial relationship. The ectoderm that will become the neural tube at the most caudal end will not have started the process of neuroectodermal differentiation, whereas the neural tube will have already been formed, and the neural crest cells would have already escaped the neural tube. The most caudal tube (the most caudal of primary neurulation) forms last.

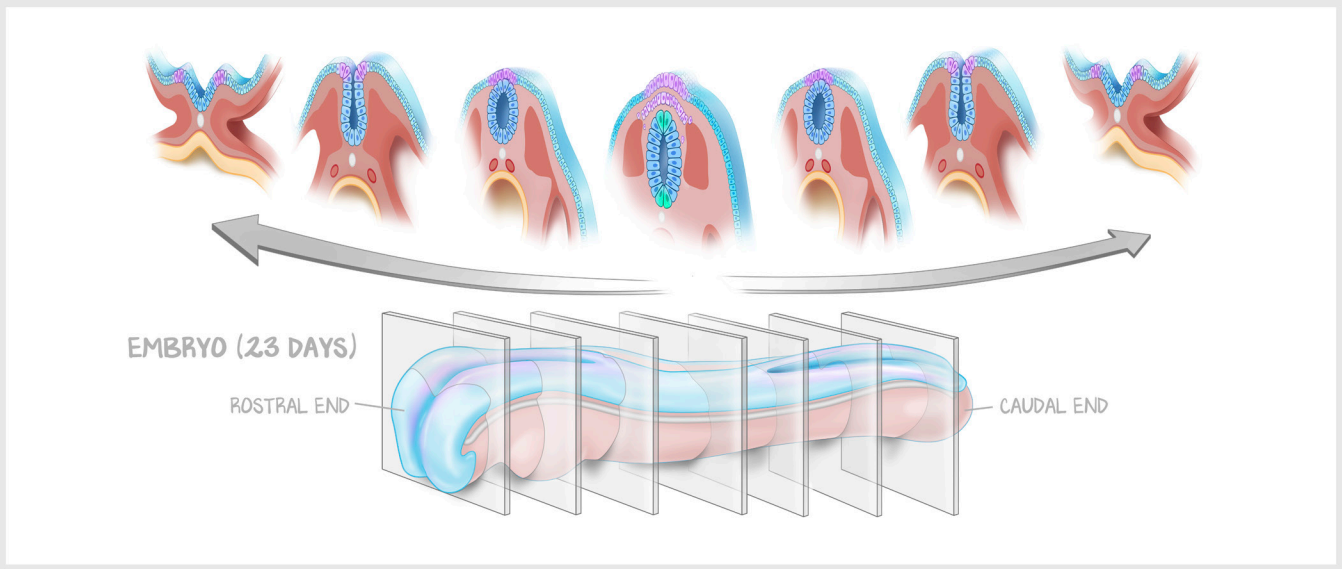

Figure 1.4: Neurulation Progression
A representational schematic of how the neural tube forms in both directions—rostrally and caudally—to form the site of first neurulation. Technically, there are two centers—one for the head, one for the spine—and the two zip up the neural tubes in both directions, but they do so while organs grow between them, pushing them apart. Effectively, it is the head that zips the head and the spine that zips the spine.

Spinal Cord Neural Crest Migration

We're taking a brief hiatus from folding and fusing to give you a breather. Neural crest cells will form the peripheral nervous system, both somatic and autonomic. They replicate to form ganglia (clusters of neurons). Endoderm forms the gut tube and lung tube, ectoderm forms the skin and hair, and mesoderm forms everything else—blood vessels, lymphatics, musculoskeletal system, etc. That means it is mostly the proliferation of mesoderm that gets the neurons and their axons to the right place. Neural crest migration can be thought of as occurring in three waves.

The first wave of migration forms the **sympathetic trunk** in front of the aorta, just outside the spinal column. It also forms **sympathetic ganglia** (including the myenteric plexus and the submucosal plexus of the GI tract), which become the **chromaffin cells** of the adrenal medulla. This is why the parasympathetic ganglia are so close to the organs they affect, and why the sympathetic ganglia (in the sympathetic trunk) are so far from their organs. It all has to do with where the cells start and what proliferation pushes them into position.

The second wave brings the **dorsal root ganglia** of the peripheral sensory neurons as well as their support cells—**Schwann cells** that myelinate and **satellite cells** that nurture axons.

The third wave sees the development of **melanocytes** in the skin.

In the head, neural crest cells do something similar. Cranial nerves V, VII, IX, and X have a sensory component to them. Similar to the peripheral sensory nerves' dorsal root ganglia (outside the spinal cord), the **sensory root ganglia** of those cranial nerves are derived from neural crest cells, although they remain within the brainstem.

Finally, neural crest cells migrate to the pharyngeal arches and do things that are not relevant here, but will be discussed in the organ systems of import.

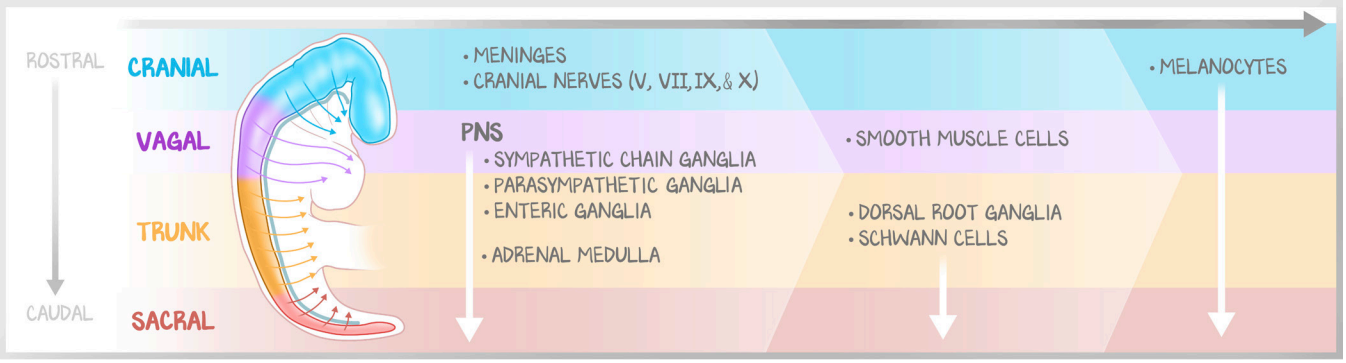

Figure 1.5: Neural Crest Cell Migration
The only cells that migrate do so very early on in development. Those cells are the neural crest cells, which go on to become the peripheral nervous system, including the sympathetic autonomics, parasympathetic autonomics, chromaffin cells of the adrenal medulla, and sensory neurons found in the dorsal root ganglion.

Neural Tube to Spinal Cord

The neural groove becomes the neural tube, and neural crest cells are derived from the crests of the neural fold. But the escaping of neural crests and formation of the neural tube doesn't happen at the same time down the length of the developing embryo. Instead, it starts in the **middle** of the organism. It then "zips up" both caudally and rostrally. The same process of neural groove ectoderm fusing to form the neural tube, neural crest migration away from the neural fold ectoderm (which fuses to form the ectoderm of skin), and mesoderm separating them from each other happens gradually and continuously. Remember "failure of neural crest migration" in GI? It is easier to depict neural crest cells as starting at the head and working their way down to reinforce the idea that Hirschsprung's myenteric plexus only makes it as far as it makes it. In reality, it is simply the failure of neural crest cells to escape the neural folds and neural groove, anywhere from the umbilicus down—a failure of mesoderm to proliferate and separate them. The process is continuous in both directions and forms a straight sheet of neural crest cells, the previous cells working to keep the continuous sheet at the crest of the neural folds behaving like neural crest cells. And since the site of neural crest migration is continuous with the subsequent ectoderm of the neural folds, the remainder of what would have been neural crest remains as ectodermal skin. Because once failed, what would have been neural crest cells becomes incorporated into either the ectoderm of the skin or the ectoderm of the neural tube.

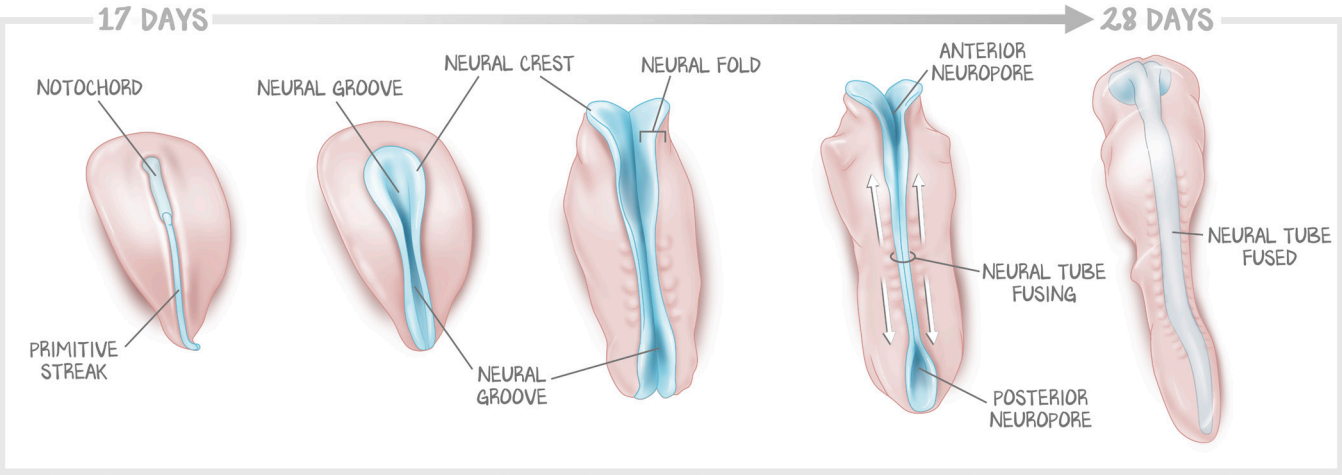

Figure 1.6: Zipping up the Neural Tube
The neural tube fuses and then zips up rostrally and caudally. The anterior neuropore will close itself (become continuous with the brain and brainstem), whereas the posterior neuropore will close by secondary neurulation via a structure in the most caudal embryo.

The **leptomeninges** (pia mater, subarachnoid space, and arachnoid mater) are derived from **neural crest cells**. Then, while the zipping up of ectoderm is happening rostrally and caudally, the cells of the neural tube proliferate. They proliferate outward against the mesoderm beside them. The mesoderm adjacent to the neural tube will form the **dura mater**. The meninges encase all central nervous structures: the brain, brainstem, and spinal cord. The mesoderm outside the dura mater will form the bones and contribute to the arteries and veins that enter the cranium through the dura and traverse the subarachnoid space

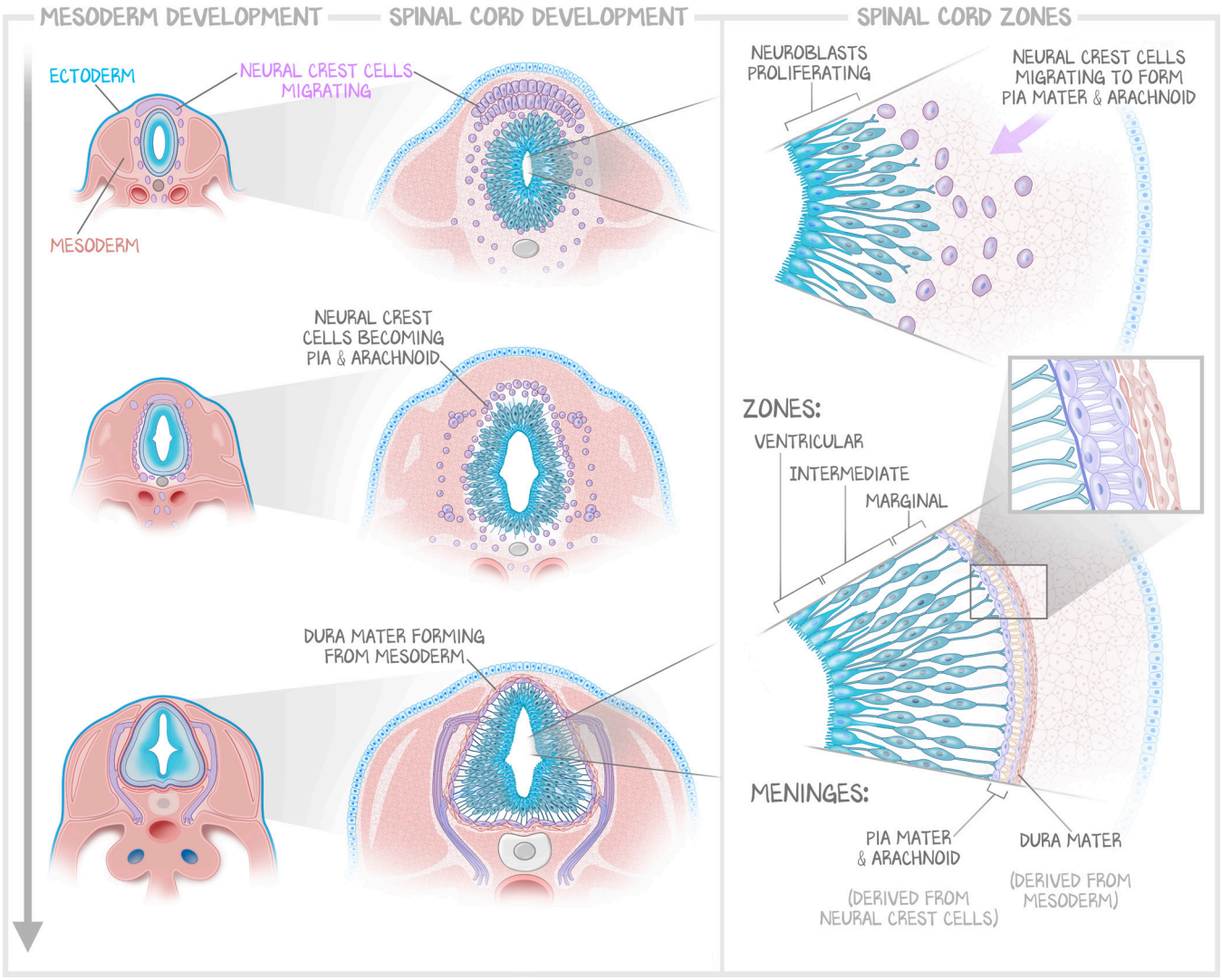

Figure 1.7: Mesodermal Changes in Response to the Neural Tube
As the neural tube proliferates to become the spinal cord, the neuroepithelial precursors remain nearest the spinal canal, and the differentiating daughter cells progress outward. The neural crest cells migrate into the nearby mesoderm. The layers of protection for the adult spinal cord are skin, bone, the dura mater, and the leptomeninges. Neural crest cells become the leptomeninges, informing the nearby mesoderm to become the dura mater, which in turn informs the next region of mesoderm to become the vertebrae. The skin will form independently, already designated as ectoderm of skin. Defects in neurulation or nearby mesoderm differentiation can result in a variety of congenital birth conditions (that you may or may not see a challenge question on).

The neuroectoderm of the neural tube proliferates. As its cells proliferate, they expand the diameter of the neural tube, and therefore the mesoderm around it, giving the entire tube inner and outer zonation. Those cells that remain adjacent to the neural canal, the canal filled with the embryonic "cerebrospinal

fluid" ("CSF," it isn't the consistency of CSF, but it helps telegraph what these cells will become) will become **ependymal cells**, the cells that line the **ventricles** and the **spinal canal** (the structures other than subarachnoid space that contain CSF). The ventricles and spinal canal are continuous from the cortex through the brainstem and spinal canal. The cells proliferating into the **intermediate zone** will become **neurons**. Neurons are not myelinated, though their axons are. Neurons are, therefore, the **grey matter** of the cortex and spinal cord. Those neurons were derived from neuroblasts (future neurons) by the dividing cells of the ventricular zone. The neurons are part of the central nervous system, so in order to remain centrally located, they must replicate and differentiate near the neural tube. As more cells are made through replication, axons and **glial cells** (support cells for axons and neurons) are pushed farther into the periphery. Glial cells take up residence in the marginal zone, where the axons are. Axons are myelinated and are the **white matter** of cortex and the spinal cord. Eventually, the neurons will come to rest on the outside of the brain, where the grey matter is located in the adult, just under the meninges. But the neurons need help—astrocytes form the boundary between the meninges (below) and the neurons—so there must be glial cells above/over/on top of the neurons. The grey matter is grey because there is no myelin, but there are many cell bodies. Those cell bodies are every type of cell—glial or neuron—except the cells that myelinate axons, the oligodendrocytes. The axons of the neurons in the grey matter are myelinated by oligodendrocytes and are white matter.

This next part is crucial to understanding tracts, brainstem nuclei, and the organization of the spinal cord. There is a bilateral structure for the entire length of the neural tube, called the sulcus limitans. The cells above (dorsal, posterior) the sulcus limitans are programmed to become sensory neurons and their supporting cells. Those cells below (ventral, anterior) the sulcus limitans are programmed to become motor neurons and their supporting cells. You cannot differentiate the sulcus limitans in a developing embryo, but we can use the concept to show you what happens. And remember, neurons grow up amongst their own kind, and their tracts don't overlap. They start the way they will end up, just with proliferation pushing them farther apart. The **alar plate** ("plate" means "area") is the **posterior cells,** and those cells will become **sensory** cells and neurons. The **basal plate** is the **anterior cells,** and those cells will become **motor** cells and neurons. For the spinal cord, the cells derived from the alar plate and the cells of the basal plate more or less stay in that orientation—sensory posterior, motor anterior. Sensory means "any signal up the spinal cord" and motor is "any signal down the spinal cord" (Motor and Sensory Tracts #1: *Motor Systems* and #2: *Sensory Systems*).

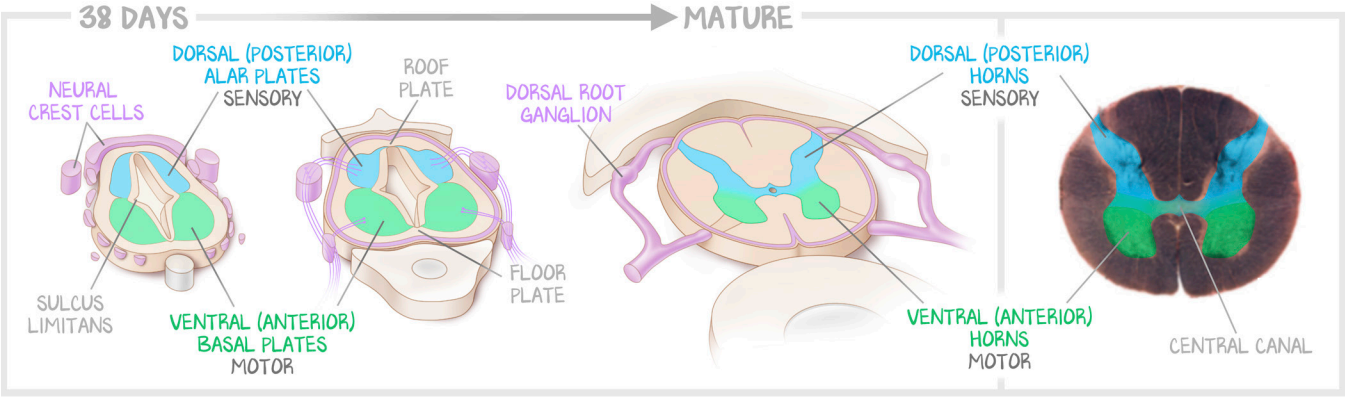

Figure 1.8: Alar and Basal Plate Set the Stage
The alar, roof, basal, and floor plates don't warrant a lot of attention on their own—this is the way things happen. But seeing "sensory posterior, motor anterior," as the foundational framework for the nervous system will help you comprehend the spinal cord and brainstem. There aren't any hard and fast rules, but seeing the relationship between the basal and alar plates relative to the central canal vs. the fourth ventricle will facilitate comprehension when we get to the heavier stuff. This lesson is less about embryogenesis and more about setting you up for success later.

Ascending Brainstem Medulla

Back to our alar and basal plates. Basal plate, anterior, motor; alar plate, posterior, sensory. In the spinal cord, a "roof plate" (the most posterior ependymal cells of the neural tube) and a "floor plate" (the most anterior cells of the neural tube) are the anterior and posterior boundaries of the spinal canal. In the brainstem, it isn't just a small canal, but rather it opens into ventricles. Ventricles and canals refer to CSF-filled structures within the parenchyma.

The bottom (rostral, inferior) of the medulla looks rather like the spinal cord. But there is a central canal, larger than the spinal canal. We don't want to get into the details of nuclei, synapses, or tracts in this discussion. This is just an introduction to the different regions of the brainstem, an orientation. There are nuclei behind the canal and nuclei in front. The ones in the back, made from the alar plate—what do you think they do? **Sensory nuclei** in the posterior. The ones in front, made from the basal plate, what about them? **Motor nuclei.**

Towards the top of the medulla, which is continuous with the bottom of the pons, is the fourth ventricle. If you were to ascend the medulla slowly, you would see the fourth ventricle start as a sliver, and progressively widen from the canal. As it does, it splits the alar plate in half and pushes it around. Quite literally, **around**. The basal plates (motor nuclei) don't move and stay anterior to the ventricle (the CSF-filled thing continuous with the canal). The ventricles push the alar plate laterally. The left goes more left, being pushed forward as it does. The right goes more right, being pushed forward as it does. The whole thing—ventricle and medulla—is still encased in mesoderm-becoming-meninges. But now, what was an anterior-posterior arrangement, has become a motor-medial, sensory-lateral arrangement. All because the ventricle moved the alar plate.

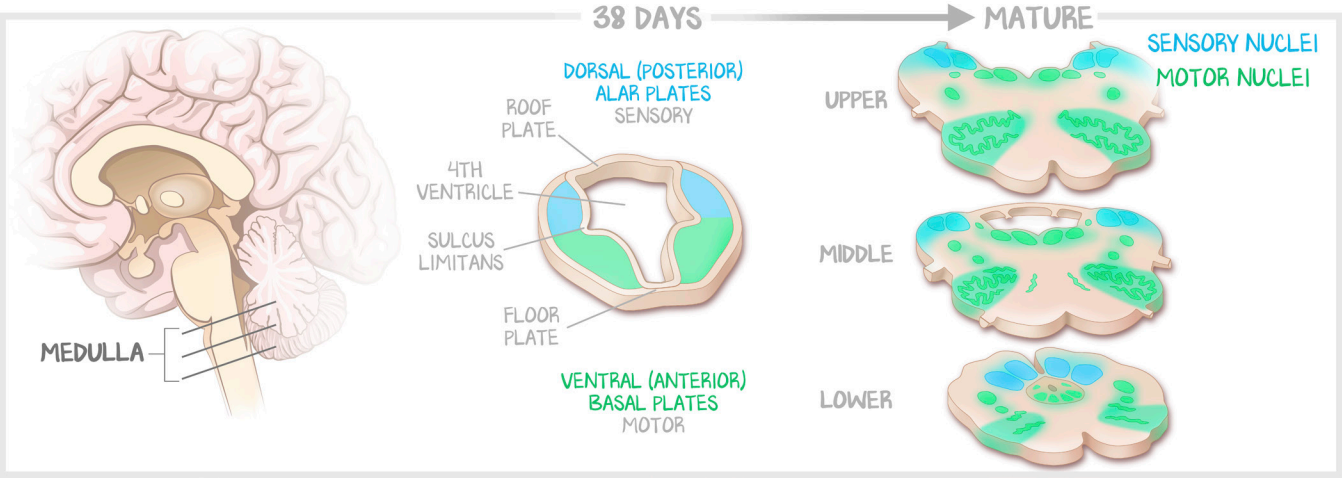

Figure 1.9: Basal and Alar Plate Concept through the Medulla
The sensory fibers from the spinal cord synapse on nuclei on their way to the cortex. They are sensory fibers, so they are blue. They synapse at the bottom of the medulla, the lower medulla. Guess where those nuclei are? The olivary nucleus is a motor nucleus. You may not know what that is yet, but what color is it going to be? It is motor, so green. And... where will it be located? Anterior and/or medial.

If you have foreseen the utility of this thought exercise already, great. If you haven't, you will. Stick with this exercise; it will make over half of Neuroscience a cakewalk.

Since the medulla is continuous with the pons, you may not find it surprising that the bottom of the pons looks like the top of the medulla. Indeed, there is a ventricle shoving the alar plate around the sides, falling laterally to the basal plate. The pons is a bit more complicated, and it manages to get some of those sensory nuclei almost anterior to the basal plate. This is because, posterior to the pons, posterior

to the ventricle, are the cerebellar peduncles. "Peduncle" means "tracts of axons." By the top of the pons, the ventricle becomes a canal again. This is where things get really difficult because we've picked up so many tracts, and so many nuclei, that it's really hard to follow them all. So we're going to cheat.

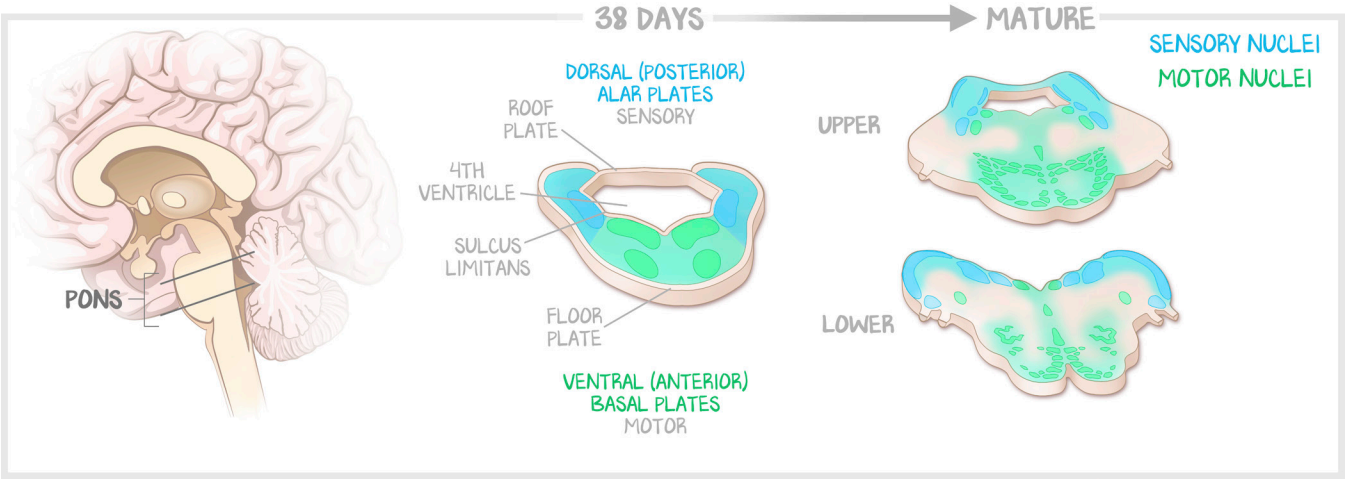

Figure 1.10: Basal and Alar Plate Concept through the Pons
Because the fourth ventricle opens the pons, the sensory nuclei that started posterior are forced around the sides. Sensory nuclei become lateral, whereas motor nuclei remain medial and anterior. This information will be crucial in understanding the cranial nerves. The vestibulocochlear nerve is a purely sensory nerve that originates at the level of the pons. Guess which color it is. Blue. Guess where the nuclei for a sensory nerve are. Lateral pons.

[Monotone airport tram announcement voice] "You have arrived. At. . . . Midbrain. Please use the posterior exit for sensory, anterior exit for motor." In the midbrain, the alar plate sends off two sets of nuclei. There is a canal here, not a ventricle. Which way do you think they go, the alar plate being sensory? Posterior, just like the announcer said. The inferior colliculus (left and right inferior colliculi) is on the back of the midbrain. It coordinates attention to sound. The superior colliculi are on the back of the midbrain, above the inferior colliculi. They coordinate attention to vision. In the anterior of the midbrain, a specialized motor tract called the substantia nigra migrates from the basal plate, in the same plane as the inferior colliculus, and a red nucleus migrates in the same plane as the superior colliculus.

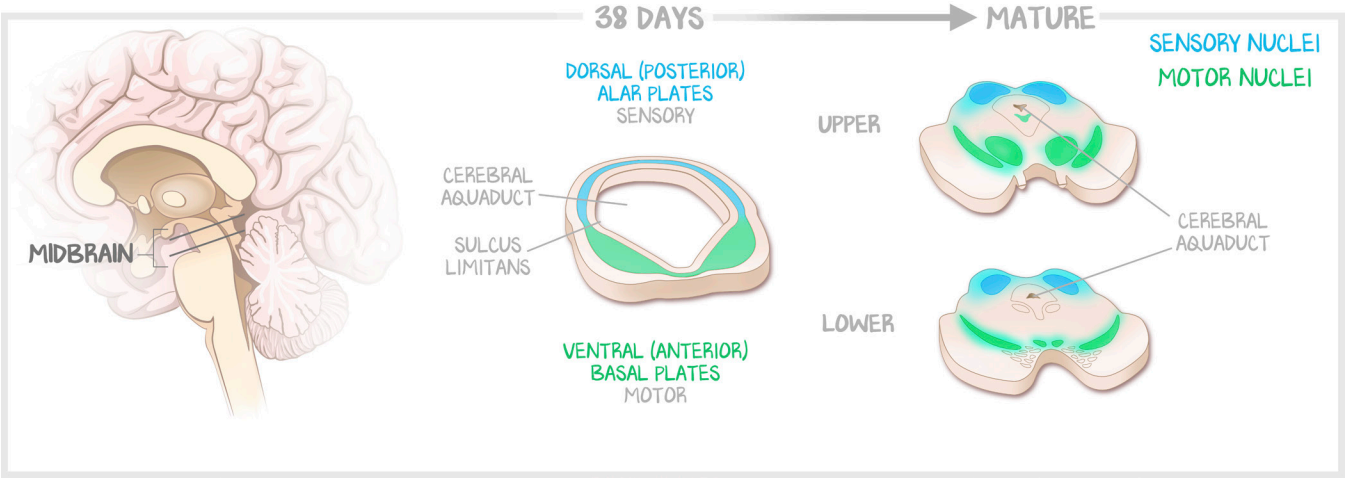

Figure 1.11: Basal and Alar Plate Concept Through the Midbrain
You don't know what the substantia nigra or the red nucleus is yet. They are the motor nuclei of the midbrain. Guess which color they are? Green. You don't know what the superior and inferior colliculi are yet. They are the sensory nuclei of the midbrain. Guess which color they are? Blue.

You finished the brainstem! Hooray! The deep brain structures are challenging. And the third ventricle has a lot going on around it. The thalamus is the relay station of sensation to the cortex, as well as of motor coordination to the cortex as part of the basal ganglia. The hypothalamus has several nuclei, some of them endocrine, some of the neural fibers of the analgesic tract. Yeah . . . better save this stuff for later. We said a lot of words that were unrelated except that they integrate at this level of the brain to show you that the complexities go way up. Above the really complicated, convoluted area that bridges cortex to brainstem is the cortex. This is supposed to be a warmup.

Neural Tube in the Head: Vesicles

We are not doing body folds. It is complicated and unhelpful for understanding tracts and nuclei. If you know the order in which the structures arise by seeing a brainstem, this next part is only perfunctory. Defects in this process are weird (cyclopia) or fatal. With neural tube defects of the cortex and brainstem rarely surviving, we want you to learn the structure and function of the CNS segments, not where they come from in embryogenesis.

The neural tube is completed via secondary neurulation. The bottom/caudal ectoderm that has been forming neural crests and neural grooves is not the entire length of the spinal cord. At the very rostral end of the embryo, through secondary neurulation, another tube-like structure grows caudally to meet the end of the neural tube. We didn't use the proper embryology words for that (neuropore, what day we're at, etc.) because we want you to home in on the things that you will actually use later in the course.

As body folds happen (magic jazz hands, scene fade, folding complete), they divide the neural tube into two bulging segments. The inside of these bulging segments is "embryologic CSF." Lining these bulging segments is the ectoderm of the neural tube, proliferating into neurons, glial cells, and ependymal cells, growing up against mesoderm that will become the meninges and skull. That's right, the same thing we said in the last section. Medical science named these bulging segments **vesicles** (because, like herpetic skin lesions, they are fluid-filled bulges). Body-folding results in **three primary vesicles**: forebrain, midbrain, and hindbrain. Really easy to understand. But instead, they were named **pro**sencephalon, **mes**encephalon, and **rhomb**encephalon. These names stuck, and so learners are left learning the -cephalons: prosencephalon becomes the **di**encephalon and the **tel**encephalon, the rhombencephalon becomes the **met**encephalon and the **myel**encephalon.

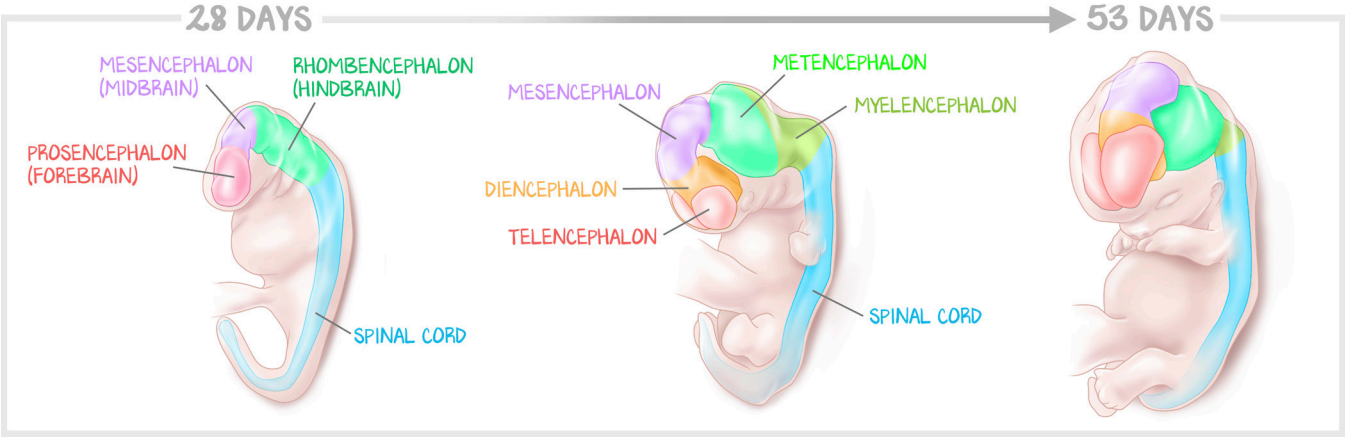

Figure 1.12: Obligatory Vesicle Stages
As you will see, we are going to use a very different vocabulary. This is the proper verbiage, and it is used in neurosurgical texts all the time. Since we figure most of you aren't going to be neurosurgeons, we thought we'd just start naming things from an easier, more clinical perspective. Radiographically, anatomically, and even determined by vasculature, we're going to refer to the cerebrum, brainstem, and deep brain (aka basal ganglia). The cerebrum is the telencephalon, the deep brain is the diencephalon, and the brainstem consists of the midbrain, pons, medulla, and cerebellum. The midbrain is the mesencephalon, the pons is the metencephalon, and the medulla is the myelencephalon. We're going to call them the midbrain, pons, and medulla.

The spinal cord is continuous with the brainstem. The tracts of the spinal cord are the same myelinated tracts in the medulla (and in the pons, and in the midbrain) as in the diencephalon. Additional nuclei will be found at different levels of the central nervous system, and those nuclei will have axons that form tracts. The central nervous system is one continuous organ. It is convenient for medical science to name the regions based on what they look like. The above figure isn't very helpful for figuring out what does what action, and what structure is represented in a real brainstem.

The spinal cord is continuous with the medulla. The medulla is continuous with the pons. You can tell which way the brainstem is oriented by the cerebellum. The cerebellum is posterior to the pons. The pons is continuous with the midbrain, and the midbrain is continuous with the deep brain, which is the gateway to the cortex. Tracts—myelinated axons—are what give these structures their shape. It is amazing how much goes on in such a little bit of space. Don't learn the -cephalons and what they become; learn the brainstem segments and how their shape is defined by the tracts and nuclei. That will be the rest of the course. This is an introductory image to get you oriented.

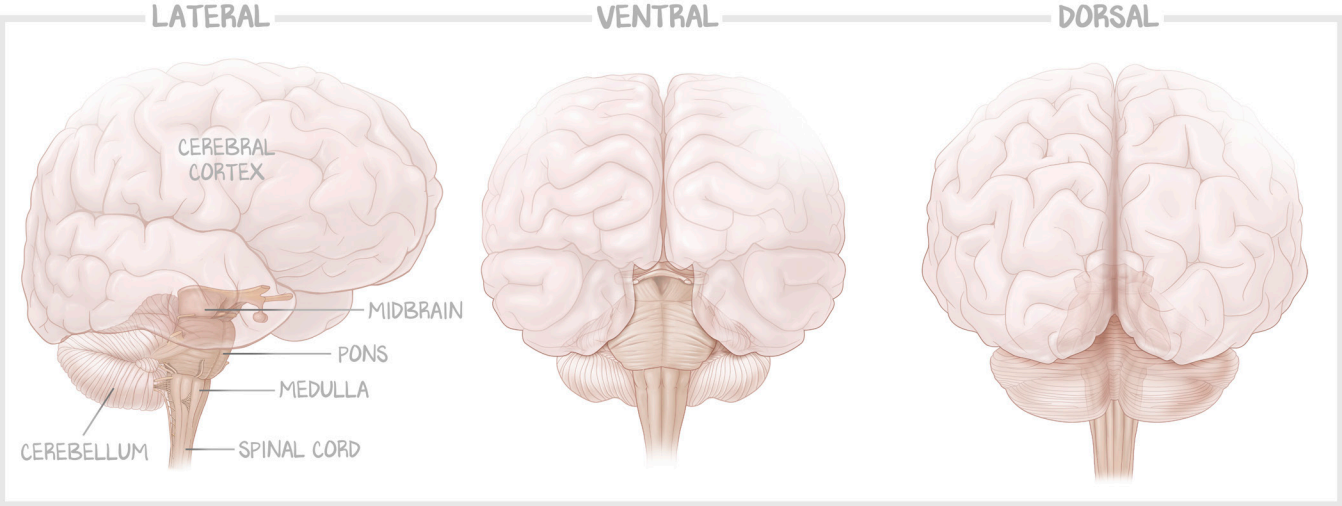

Figure 1.13: The Better Way to Consider the CNS
The cerebrum is the squishy thing you think of when someone says brain. The brainstem is the midbrain, pons, and medulla. The cerebellum is down there, too. What connects the cerebrum to the brainstem is the deep brain.

Citations

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